

**MULTIMEDIA**



**UNIVERSITY**

**STUDENT ID NO**

--	--	--	--	--	--	--	--	--	--

# **MULTIMEDIA UNIVERSITY**

## **FINAL EXAMINATION**

**TRIMESTER 2, 2019/2020**

**ENT3036 – SEMICONDUCTOR DEVICES**  
(NE)

02 MARCH 2020  
2.30 pm – 4.30 pm  
(2 Hours)

---

### **INSTRUCTION TO STUDENTS**

1. This Question paper consists of 6 pages with 4 Questions only.
2. Answer all the questions and all the questions carry equal marks of 25. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

**Question 1**

- (a) Consider a uniformly doped GaAs junction at  $T = 300$  K. At zero bias, 10 percent of the total space charge region is to be in the  $p$ -region. The built-in potential barrier is  $V_{bi} = 1.2$  V. For zero bias, determine the followings:
- (i) Acceptor concentration,  $N_a$
  - (ii) Donor concentration,  $N_d$
  - (iii) Space charge width in the  $n$ -type region,  $x_n$
  - (iv) Space charge width in the  $p$ -type region,  $x_p$
- [7 marks]
- (b) Tunnel diode, also known as Esaki diode is named after Leo Esaki, who received the Nobel Prize in physics for discovering the electron tunneling effect used in these diodes. Draw the band diagram of a tunnel diode. Explain briefly the operation when a slight forward bias is applied.
- [6 marks]
- (c) With the help of the diagram, explain in detail the minority carrier distribution in an npn bipolar transistor operating in the forward-active mode.
- [7 marks]
- (d) A uniformly doped silicon pnp bipolar transistor is biased in the inverse active mode at 300 K. The metallurgical base width is  $1.10 \mu\text{m}$ . The transistor doping are  $N_E = 5 \times 10^{17} \text{ cm}^{-3}$ ,  $N_B = 10^{16} \text{ cm}^{-3}$  and  $N_C = 5 \times 10^{14} \text{ cm}^{-3}$ .
- (i) State the biasing conditions for B-C junction and B-E junction for the transistor.
  - (ii) What is the maximum B-C voltage so that the low-injection condition applies? Assume the low injection limit is reached when  $p_c(0) = 0.1N_C$ .
- [5 marks]

Continued ...

**Question 2**

- (a) JFET is a unipolar transistor which allows only one type of carriers (majority carriers) in the operation and to contribute to the current.

(i) Draw and label the detail structure, biasing of a double gate n-channel pn junction FET. What is the type of carrier for the JFET.

[5 marks]

(ii) Explain the pinchoff effects in the n-channel JFET with proper diagram and current voltage characteristics.

[6 marks]

- (b) When  $V_{DS} = 0$ , for n channel one-sided  $p^+n$  junction, space charge width is

$$h = \left[ \frac{2\epsilon(V_{bi} - V_{GS})}{eN_D} \right]^{\frac{1}{2}}$$

where  $V_{GS}$  is the gate to source voltage. Calculate the internal pinchoff voltage and the pinchoff voltage for the uniformly doped silicon n-channel JFET at 300 K. The doping concentration are  $N_a = 10^{18} \text{ cm}^{-3}$  and  $N_d = 10^{16} \text{ cm}^{-3}$ . The channel thickness is  $0.75 \mu\text{m}$ .

[5 marks]

- (c) What is the cutoff frequency in JFET? Name the two frequency limitation factors in a JFET.

[3 marks]

- (d) Explain two types of non-ideal effects that will change the ideal device characteristics in JFET.

[3+ 3 marks]

**Continued...**

**Question 3**

- (a) Explain the accumulation, depletion and inversion of metal oxide semiconductor (MOS) capacitors with  $n$ -type substrate with the aid of energy-band diagrams at
- a positive gate bias
  - a moderate negative gate bias
  - a large negative gate bias.

Subsequently, draw the ideal capacitance versus gate voltage/ $C$ - $V$  characteristics of the MOS capacitor and label each biasing region accordingly. [9+4 marks]

- (b) The metal-silicon work function difference versus doping for aluminum, gold and polysilicon gates are shown in Fig. Q3

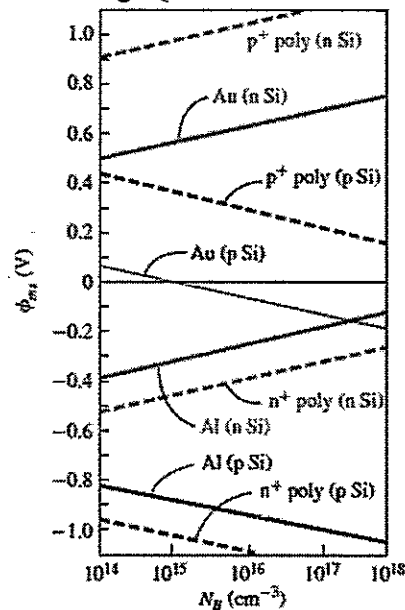


Fig. Q3

A MOS device with Al gate is fabricated on a  $p$ -type Si substrate with doping concentration  $10^{17} \text{ cm}^{-2}$ . The silicon dioxide thickness  $t_{\text{ox}} = 20 \text{ nm}$ , and the trapped oxide charge  $Q'_{\text{ss}} = 4 \times 10^{10}$  electronic charges per cm.

- Calculate  $\phi_{\text{fp}}$ ,  $C_{\text{ox}}$  and  $Q'_{\text{ss}}$ .
  - Given  $x_{\text{dT}}$  (the maximum space charge width) is  $1.6 \times 10^{-5} \text{ cm}$ , obtain  $\phi_{\text{ms}}$  from Fig. Q3 and calculate  $Q'_{\text{SD}}(\text{max})$  (the maximum space charge in the depletion region) and the threshold voltage  $V_{\text{TN}}$ . Is the device an enhancement mode or depletion mode device? [3+6 marks]
- (c) An ideal  $n$ -channel MOSFET is operated in the nonsaturation region with the following parameters: channel width is  $22.5 \mu\text{m}$ , length is  $3 \mu\text{m}$ ,  $C_{\text{ox}} = 6.9 \times 10^{-8} \text{ F/cm}^2$ ,  $V_{\text{DS}} = 0.10 \text{ V}$ ,  $I_{\text{D}} = 35 \mu\text{A}$  at  $V_{\text{GS}} = 1.5 \text{ V}$  and  $I_{\text{D}} = 75 \mu\text{A}$  at  $V_{\text{GS}} = 2.5 \text{ V}$ . Calculate the inversion carrier mobility. [3 marks]

Continued ...

**Question 4**

- (a) What is the frequency range for microwave? [1 marks]
- (b) Gunn diode or Transferred-Electron Device (TED) is used to generate microwave signal.
- (i) List three differences between Gunn diode and normal transistor [6 marks]
  - (ii) Draw a diagram of a simplified two-terminal GaAs Gunn diode with proper biasing. Label accordingly. [3 marks]
  - (iii) With diagrams of energy band structure and the IV curve of a Gunn diode; explain negative differential resistance. Label the threshold voltage, the maximum operating voltage and the oscillation region. [10 marks]
- (c) Sketch and label the structure of an IMPATT diode that has a drift region length of  $10\text{ }\mu\text{m}$ . The drift velocity for holes is  $10^7\text{ cm/s}$  and the drift velocity for electron is  $9 \times 10^6\text{ cm/s}$ . Calculate the optimum operating frequency for the diode. [5 marks]

**Continued...**

**PHYSICAL CONSTANTS:**

Thermal voltage:	$V_t = 0.0259 \text{ V}$
Intrinsic concentration of Silicon at 300K:	$n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$
Intrinsic concentration of Silicon at 373K:	$n_i = 2.5 \times 10^{12} \text{ cm}^{-3}$
Intrinsic concentration of Gallium Arsenide at 300K:	$n_i = 1.8 \times 10^6 \text{ cm}^{-3}$
Boltzmann's constant:	$k = 1.3806 \times 10^{-23} \text{ J/K}$
Electronic charge:	$e = 1.6 \times 10^{-19} \text{ C}$
Permittivity of free space:	$\epsilon_0 = 8.85 \times 10^{-14} \text{ F/cm}$
Dielectric constant of Silicon at 300K:	$\epsilon_r = 11.7$
Dielectric constant of Silicon oxide at 300K:	$\epsilon_i = 3.9$
Dielectric constant of Gallium Arsenide at 300K:	$\epsilon_{\text{GaAs}} = 13.1$

**End of paper.**



